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A method of and a device for actively reducing the sound level in a region of a space

THE BACKGROUND OF THE INVENTION AND PRIOR ART

The present invention refers to a method of actively reducing the level of a primary field of sound or vibration in a space, comprising the steps of: providing a first number of actuators in the space to produce a secondary field of sound or vibration, which is adapted to interfere with the primary field; providing a second number of control sensors in the space to sense a parameter related to the residual level of the primary field and the secondary field; and determining a first transfer matrix defining for each control sensor the level of the parameter caused by a certain level of the excitation from each actuator.

Moreover, the present invention refers to a device for actively reducing the level of a primary field of sound or vibration in a space, comprising a first number of control sensors provided in the space to sense a parameter related to the residual level of the primary field and the secondary field; a second number of actuators provided in the space to produce a secondary field of sound or vibration, which is adapted to interfere with the primary field; and a first determining means provided to determine a first transfer function matrix defining for each control sensor the level of the parameter caused by a certain level of the excitation from each actuator.

It is known to reduce the level of a primary field of noise in a space by means of a set of actuators provided to

produce a secondary field of sound to interfere with the primary field. Thereby, a set of control sensors is provided in the space at the locations where a maximum reduction is desired. A control unit provides such a force at each actuator that the sound level at the control sensors is reduced to a minimum level.

Such a known noise reduction method is effective to reduce the noise at the location of the control sensors, whereas the noise level in the space at positions removed from the control sensors is not directly controllable by the method. In addition, the noise level at positions removed from the control sensors may be significant, and at certain locations the secondary field may, instead of reducing the primary field, interfere in such a way that the total level of the combined fields is higher than the level of the primary field alone. By the known method, it is thus necessary to position the control sensors immediately adjacent to the locations at which an essential noise reduction is desirable. For several reasons, such a positioning of the control sensors is not possible.

US-A-5 381 485 discloses a device for actively reducing the sound or noise level in a specific region of a space. The device of this document comprises a loudspeaker which is intended to generate sound waves to interfere with unwanted sound waves and thereby produce a region having a substantially reduced sound level. Furthermore, a control microphone, located closer to the loudspeaker than the region, is provided to sense the sound in the space. A loudspeaker control means has an input connected to the control microphone and an output connected to the loudspeaker for operating the latter. The loudspeaker control means comprises a signal processing means arranged to simulate a virtual microphone signal that would have been obtained if the microphone were to be positioned in said

region, i.e. where it is desired to reduce the sound level. The simulated signal is used to control the loudspeaker. However, the technique presented in this document in reality merely appears to be applicable to one microphone and one loudspeaker. Furthermore, the known solution may only be employed when the control microphone and the virtual microphone are located at a relatively small distance from each other in relation to the acoustic wave length, i.e. significantly shorter than the acoustic wave length.

SUMMARY OF THE INVENTION

The object of the present invention is to provide an improved reduction of the noise and/or vibration level in a space. In particular, it is aimed at a reduction of the noise and/or vibration level at an arbitrary position in a space.

This object is obtained by the method initially defined and characterized by providing, during an initial, provisional period of time, a third number of monitor sensors in the space to sense the parameter related to the level of the primary field, determining a second transfer matrix defining for each monitor sensor the level of the parameter caused by a certain level from each actuator, and controlling the actuators by means of a force vector being a function of the first transfer matrix, a first projection matrix reflecting the relation between the first transfer matrix and said second transfer matrix, a second projection matrix reflecting the relations between the parameter sensed by the control sensors and the parameter sensed by said monitor sensors, and a residual vector of the actual level of the parameter at the control sensors.

By such a method it is possible to provide an arbitrary number of actuators, control sensors and monitor sensors,

and thereby take into account the complexity of the fields in such a manner that a significant reduction of the noise or vibration level is obtained in the space at the location of the monitor sensors, which may be located in a position where it is not practically possible to provide control sensors, for instance at the location of a passenger in an aircraft cabin. According to the method of the invention, the control sensors are projected to the monitor sensors.

According to an embodiment of the present invention, said monitor sensors are provided at a respective position at which a significant reduction of the level of the primary field is desired. Thereby, the control sensors may be provided at a distance from the positions of said monitor sensors.

According to a further embodiment of the present invention, said force vector is advantageously produced by a multiplication of the pseudo inverse of the first transfer matrix, said first projection matrix, the pseudo inverse of said second projection matrix, and said residual vector. Consequently, an effective control function for controlling the forces to be applied to the actuators may be achieved by simple matrix multiplication, which may be performed by conventional computer means.

According to a further embodiment of the present invention, the number of control sensors is reduced in the first projection matrix and the second projection matrix to include only an optimal set of sensors for projecting each monitor sensor. In such a manner, it is possible to improve the projection of the control sensors to the monitor sensors by using only the most significant control sensors.

The object is also obtained by the device initially defined and characterized by a third number of monitor sensors

arranged to be provided in the space during an initial, provisional period of time to sense the parameter related to the level of the primary field, second determining means provided to determine a second transfer matrix defining for each monitor sensor the level of the parameter caused by a certain level of the excitation from each actuator, and a control unit provided to control the actuators by means of a force vector being a function of the first transfer matrix, a first projection matrix reflecting the relation between the first transfer matrix and said second transfer matrix, a second projection matrix reflecting the relations between the parameter sensed by the control sensors and the parameter sensed by said monitor sensors, and a residual vector of the actual level of the parameter at the control sensors.

Preferred embodiments of the device are defined in the dependent claims 9 - 12.

BRIEF DESCRIPTION OF THE DRAWING

The present invention is now to be described more closely by means of a preferred embodiment, merely disclosed by way of example, and with reference to the drawing attached hereto, in which Fig 1 shows a schematic cross-sectional view of an aircraft cabin having a device according to the invention for reducing the noise level.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE PRESENT INVENTION

Fig 1 discloses a cross-section through an aircraft body 1, comprising an inner space in the form of a conventional passenger cabin 2. The passenger cabin 2 is delimited by an inner wall 3 and a floor 4. In the passenger cabin 2, there are provided a plurality of seat rows merely one of which is

disclosed in Fig 1. Each seat row comprises four seats 5. During flight, a primary field of sound or noise in the passenger cabin 2 is produced by the operation of the aircraft.

According to the present invention, a device is provided in the passenger cabin 2 in order to reduce the level of the primary field. The device comprises a number of actuators 6 which are distributed along the inner wall 3 and the floor 4. In the embodiment disclosed the actuators 6 are realized as loudspeakers arranged to produce a secondary field of sound. The secondary field is adapted to interfere with said primary field. Furthermore, the device comprises a number of control sensors 7 which are distributed along the inner wall 3 and the floor 4. In the embodiment disclosed, the control sensors 7 are realized as microphones arranged to sense the residual level of the pressure caused by the primary field and the secondary field.

Each actuator 6 and each control sensor 7 is connected via a conduit 8 and 9, respectively, to a control unit 10. The control unit 10 may comprise an input member 11, provided to receive signals from the control sensors 7 and to convert the signals to a suitable digital form; a computerized processing member 12, provided to process said converted signals; and an output member 13, provided to convert the processed signals to a suitable form and to transmit these signals to a respective actuator 6. Furthermore, said control unit 10 comprises a memory member 14 including a memory of the type RAM and connected to the processing member 12.

In the embodiment disclosed, four regions 15 have been indicated, in which the ears of the passengers present in the passenger cabin 2 normally are located during flight. Thus, it is particularly important to reduce the noise level

in these regions 15. A number of monitor sensors 16, in the form of monitor microphones, is arranged in the regions 15 during an initial preparing period before the device is employed for noise reduction. It is to be noted that the monitor sensors 16 may be removed from the passenger cabin 2 after the performance of such measurements and during operation of the device. The provisionally provided monitor sensors 16 are also connected to the control unit 10 during said preparing period and arranged to sense the pressure level caused by a certain force applied to the actuators 6. During this preparing or measurement period the level of the primary field is essentially equal to zero.

The numbers of control sensors 7, actuators 6 and monitor sensors 16 may vary depending on the actual conditions, for instance the size and the complexity of the passenger cabin 2. Although not a requirement, in the embodiment disclosed the number of control sensors 7 is higher than the number of actuators 6. According to an example, the number of actuators 6 may be 36, the number of control sensors 7 may be 72, and the number of monitor sensors 16 may be 70.

As an example of a simple and commonly used control strategy, the forces, found by using the LMS algorithm, can be written and will be used:

$$\mathbf{F}_{i+1} = \mathbf{F}_i - \mathbf{H}_c^{+}\,\mathbf{E}_{ci} \qquad \text{(a)}$$

where *i* is an index indicating the time step in the update of the equation in the controller and

$\mathbf{E}_c$ is a residual vector of the actual level of the pressure at each control sensor 7, (b)

$\mathbf{H}_c$ is a first matrix defining the transfer function from each actuator 6 to each control sensor 7, (c)

$\mathbf{F}$ is a force vector defining the forces to be (d)

applied to each actuator 6, and

$\mathbf{H_c^+}$ is an pseudo inverse of the first transfer function matrix $\mathbf{H_c}$. (e)

Consequently, the control function (a), in the embodiment disclosed, is realized by the LMS-algorithm (Least Mean Square). Moreover, other types of the LMS-algorithms may be employed, for instance a so called leaky LMS-algorithm. Within the scope of the present invention also other algorithms may be employed, for instance a RLS-algorithm (Recursive Least Square).

However, since it is desirable to obtain a maximal reduction of the noise level in the regions 15, it would be desirable to control the actuators 6 by a signal sensed by a monitor sensor 16, i.e. according to the control function

$$\mathbf{F}_{i+1} = \mathbf{F}_i - \mathbf{H}_m^+ \mathbf{E}_{mi} \qquad \text{(f)}$$

where

$\mathbf{H_m}$ is a second matrix defining the transfer function from each actuator 6 to each monitor sensor 16, (g)

$\mathbf{H_m^+}$ is the pseudo inverse of the second transfer function matrix $\mathbf{H_m}$, and (h)

$\mathbf{E_m}$ is a residual vector of the actual level of the pressure at each monitor sensor 16. (i)

As indicated above, the monitor sensors 16 are not employed during flight and therefore the matrix $\mathbf{H_m}$ is determined in advance by means of the processing member 12 of the control unit 10 during the above-identified preparing period and is stored in the memory member 14.

It is assumed that a projection matrix $\mathbf{P_H}$ may be set up as

$$\mathbf{P}_H = \mathbf{H}_c \mathbf{H}_m^+ \qquad (j)$$

where

$\mathbf{P}_H$ is a first projection matrix reflecting the relation between the transfer matrix $\mathbf{H}_c$ and the transfer matrix $\mathbf{H}_m$.

Furthermore, it is assumed that a projection matrix $\mathbf{P}_U$ may be set up where

$$\mathbf{U}_c = \mathbf{P}_U \mathbf{U}_m$$

where

$\mathbf{P}_U$ is a second projection matrix reflecting the relation between the pressure level at each control sensor 7 and the pressure level at each monitor sensor 16 due to the primary field, (k)

$\mathbf{U}_c$ is a vector of the actual level of the pressure at each control sensor 7 due to the primary field, and (l)

$\mathbf{U}_m$ is a vector of the actual level of the pressure actual level of the pressure at each monitor sensor 16 due to the primary field. (m)

Consequently, the residual force may hence be defined by the control function

$$\mathbf{F}_{i+1} = \mathbf{F}_i - \mathbf{H}_c^+ (\mathbf{P}_H \mathbf{P}_U^+) \mathbf{E}_{ci} \qquad (n)$$

where

$\mathbf{P}_U^+$ is the pseudo inverse of the second projection matrix $\mathbf{P}_U$. (o)

Also $\mathbf{P_H}$ and $\mathbf{P_U}^+$ may be calculated by the processing member 12 and stored in the memory member 14.

Consequently, the noise reduction according to the control function (n) takes into account the fact that the control sensors 7 are not located in the regions 15 where a maximum noise reduction is desired.

The device according to the invention permits a large number of control sensors and monitor sensors 16 to be utilized, and thus it is possible to effectively reduce the noise at an arbitrary location within the space 2 defined.

The determination of the first projection matrix (j) for the control function (n) is an error minimization of the predicted response compared to the actual response of the monitor sensors 16. Initially, the first projection matrix $\mathbf{P_H}$ as defined takes into account all control sensors 7. In a subsequent operation, an optimal set of control sensors 7 is obtained for projecting each monitor sensor 16. Thereby, it is possible to reduce the number of control sensors 7 to include only the best control sensors 7 in the control function (n).

Furthermore, the full set of control sensors 7 in the second projection matrix $\mathbf{P_U}$ is reduced to include only the most significant control sensors 7 in the pseudo inverse of the first projection matrix $\mathbf{P_H}$ for a given monitor sensor 16. The selected control sensors are used in (k) and an iterative process is used to populate the second projection matrix $\mathbf{P_U}$.

During operation of the device according to the invention, the control function (n) is continuously updated according to an appropriate iteration algorithm, at least with regard to the residual vector $\mathbf{E_C}$ and potentially with regard to the

transfer matrix $\mathbf{H}_C$. This means that an actual level of the force vector F is continuously calculated and applied to the actuators 6.

The control function (n) described above is defined for calculations in a frequency plane, which means that a control function (n) is utilized for each frequency to be reduced. It is to be noted that the invention may also be applied to a control function in a time plane. In an example for noise reduction in an aircraft, it is considered appropriate to reduce three different frequencies or frequency intervals.

The present invention is not limited to the embodiment described herein but may be varied and modified within the scope of the following claims.

Although the embodiment disclosed refers to the reduction of sound or noise, it is to be noted that the invention is applicable to the reduction of vibrations as well. In this case the control sensors 7 may be arranged to sense a vibration, and the actuators may comprise shakers.

Although the device and the method according to the invention have been described in connection with noise reduction in aircraft, it is to be noted that the invention is also applicable to other spaces, rooms in houses or buildings, passenger cabins in vehicles, such as cars, etc.

Claims

1. A method of actively reducing the level of a primary field of sound or vibrations in a space (2), comprising the steps of:
providing a first number of actuators (6) in the space (2) to produce a secondary field of sound or vibration, which is adapted to interfere with the primary field;
providing a second number of control sensors (7) in the space (2) to sense a parameter related to the residual level of the primary field and the secondary field; and
determining a first transfer matrix (c) defining for each control sensor (7) the level of the parameter caused by a certain level of excitation from each actuator (6),
characterized by
providing, during an initial, provisional period of time, a third number of monitor sensors (16) in the space (2) to sense the parameter related to the level of the primary field;
determining a second transfer matrix (g) defining for each monitor sensor (16) the level of the parameter caused by a certain level from each actuator (6); and
controlling the actuators (6) by means of a force vector (F) being a function (n) of the first transfer matrix (c), a first projection matrix (j) reflecting the relation between the first transfer matrix (c) and said second transfer matrix (g), a second projection matrix (k) reflecting the relations between the parameter sensed by the control sensors (7) and the parameter sensed by said monitor sensors (16), and a residual vector (b) of the actual level of the parameter at the control sensors (7).

2. A method according to claim 1, characterized by providing said monitor sensors (16) at respective positions (15) at which a significant reduction of the level of the primary field is desired.

3. A method according to claim 2, <u>characterized by</u> providing the control sensors (7) at locations removed from the positions (15) of said monitor sensors (16).

4. A method according to any one of the preceding claims, <u>characterized by</u> producing said force vector (F) by the multiplication of the pseudo inverse of the first transfer matrix (e), said first projection matrix (j), the pseudo inverse of the said second projection matrix (o), and said residual vector (b).

5. A method according to any one of the preceding claims, <u>characterized by</u> reducing the number of control sensors (7) included in the first projection matrix (j) and the second projection matrix (o) to include only an optimal set of control sensors (7) for projecting each monitor sensor (16).

6. A method according any one of the preceding claims, <u>characterized in</u> that the parameter comprises a pressure.

7. A method according to any one of the preceding claims, <u>characterized in</u> that the parameter comprises a vibration.

8. A device for actively reducing the level of a primary field of sound or vibration in a space (2), comprising
a first number of control sensors (7) provided in the space (2) to sense a parameter related to the residual level of the primary field and the secondary field;
a second number of actuators (6) provided in the space (2) to produce a secondary field of sound or vibrations, which is adapted to interfere with the primary field;
a first determining means provided to determine a first transfer function matrix (c) defining for each control sensor (7) the level of the parameter caused by a certain level of the excitation from each actuator (6),

characterized by
a third number of monitor sensors (16) arranged to be provided in said space (2) during an initial, provisional period of time to sense the parameter related to the level of the primary field;
a second determining means provided to determine a second transfer matrix (g) defining for each monitor sensor (16) the level of the parameter caused by a certain level from each actuator (6); and
a control unit provided to control the actuators (6) by means of a force vector (F) being a function (n) of the first transfer matrix (c), a first projection matrix (j) reflecting the relation between the first transfer matrix (c) and said second transfer matrix (g), a second projection matrix (k) reflecting the relations between the parameter sensed by the control sensors (7) and the parameter sensed by said monitor sensors (16), and a residual vector (b) of the actual level of the parameter at the control sensors (7).

9. A device according to claim 8, characterized in that said monitor sensors (16) are provided to be arranged during a preparing period of time at respective positions (15) at which a significant reduction of the level of the primary field is desired.

10. A device according to claim 9, characterized in that the control sensors (7) are provided at positions removed from the positions (15) of said monitor sensors (16).

11. A device according to any one claims 8 to 10, characterized in that said control unit (10, 12) is arranged to produce said force vector (F) by the multiplication of the pseudo inverse of the first transfer matrix (e), said first projection matrix (j), the pseudo inverse of the said second projection matrix (o), and said residual vector (b).

12. A device according to any one of claims 8 to 11, <u>characterized in</u> that said control unit (10, 12) is arranged to reduce the number of control sensors (7) included in the first projection matrix (j) and the second projection matrix (o) to include only an optimal set of control sensors (7) for projecting each monitor sensor (16).

Abstract

The invention concerns a method and a device for actively reducing the level of a primary field of sound or vibration in a space (2). Control sensors (7) sense a parameter related to said level. Actuators (6) produce a secondary field of sound or vibration interfering with said primary field. A first transfer function matrix defines for each control sensor the level of the parameter caused by a certain level of the actuator excitation. Monitor sensors (16) sense during an initial, provisional period of time said parameter related to the level of the primary field. A second transfer matrix defines for each monitor sensor (16) the level of the parameter caused by a certain level of actuator excitation. A control unit (10) controls the actuators (6) by a force vector being a function of the first transfer matrix, a first projection matrix reflecting the relation between the first transfer matrix and the second transfer matrix, a second projection matrix reflecting the relations between the parameter sensed by the control sensors (7) and the parameter sensed by the monitor sensors (16), and a residual vector of the actual level of the parameter at the control sensors.

(Fig 1)

Fig 1

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